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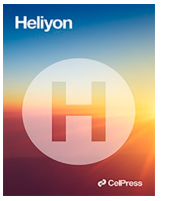

Research article

A one-year relapse prediction model for acute ischemic stroke (AIS) based on clinical big data

Wenle Li [a,b,1], Zhendong Ding [c,1], Liangqun Rong [b,d,1], Xiu'e Wei [b,d], Chenyu Sun [e], Scott Lowe [f], Muzi Meng [g,h], Chan Xu [a], Chengliang Yin [i], Haiyan Liu [b,d], Wencai Liu [j,*], Qian Zhou [k,**], Kai Wang [b,d,***]

[a] *The State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics & Center for Molecular Imaging and Translational Medicine, School of Public Health, Xiamen University, Xiamen, China*
[b] *.Key Laboratory of Neurological Diseases, The Second Affiliated Hospital of Xuzhou Medical University, Xuzhou, Jiangsu, China*
[c] *Department of Anesthesiology, The Third Affiliated Hospital of Sun Yat-sen University, No. 600 Tianhe Road, Guangzhou, 510630, China*
[d] *Department of Neurology, The Second Affiliated Hospital of Xuzhou Medical University, Xuzhou, Jiangsu, China*
[e] *Department of Thyroid and Breast Surgery, the Second Affiliated Hospital of Anhui Medical University, Hefei, Anhui, China*
[f] *College of Osteopathic Medicine, Kansas City University, 1750 Independence Ave, Kansas City, MO 64106, USA*
[g] *UK Program Site, American University of the Caribbean School of Medicine, Vernon Building Room 64, Sizer St, Preston PR1 1JQ, United Kingdom*
[h] *Bronxcare Health System, 1650 Grand Concourse, The Bronx, NY 10457, USA*
[i] *Faculty of Medicine, Macau University of Science and Technology, Macau, China*
[j] *Department of Orthopaedics, Shanghai Jiao Tong University Affiliated Sixth People's Hospital, 600 Yishan Road, Shanghai 200233, China*
[k] *Department of Respiratory and Critical Care Medicine, People's Hospital of Chongqing Liang Jiang New Area, Chongqing, China*

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ABSTRACT

Objective: To develop and evaluate a nomogram prediction model for recurrence of acute ischemic stroke (AIS) within one year.
Method: Patients with AIS treated at the second affiliated hospital of Xuzhou Medical University from August 2017 to July 2019 were enrolled. Clinical data such as demographic data, risk factors, laboratory tests, TOAST etiological types, MRI features, and treatment methods were collected. Cox regression analysis was done to determine the parameters for entering the nomogram model. The performance of the model was estimated by receiver operating characteristic curves, decision curve analysis, calibration curves, and C-index.
Result: A total of 645 patients were enrolled in this study. Side of hemisphere (SOH, Bilateral, HR = 0.35, 95 % CI = 0.15–0.84, p = 0.018), homocysteine (HCY, HR = 1.38, 95 % CI = 1.29–1.47, p < 0.001), c-reactive protein (CRP, HR = 1.04, 95 % CI = 1.01–1.07, p = 0.013) and stroke severity (SS, HR = 3.66, 95 % CI = 2.04–6.57, p < 0.001) were independent risk factors. The C-index of the nomogram model was 0.872 (se = 0.016). The area under the receiver operating characteristic (ROC)curve at one-year recurrence was 0.900. Calibration curve, decision curve analysis showed good performance of the nomogram. The cutoff value for low or high risk of recurrence score was 1.73.

* Corresponding author.
** Corresponding author.
*** Corresponding author.
E-mail addresses: liuwencaincu@163.com (W. Liu), zhouqian0906@163.com (Q. Zhou), wk1982405@163.com (K. Wang).
[1] These authors have contributed equally to this work.

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Conclusion: The nomogram model for stroke recurrence within one year developed in this study performed well. This useful tool can be used in clinical practice to provide important guidance to healthcare professionals.

1. Introduction

Acute ischemic stroke (AIS) is the main type of stroke [1]. It is caused by cerebral artery stenosis or occlusion. Lack of oxygen and nutrient supply causes complex biochemical and molecular events leading to ischemic necrosis of brain tissue [2]. Treatment options include thrombolytic therapy, revascularization therapy and neuroprotective therapy [3]. AIS is characterized by high morbidity, disability and mortality, resulting in a huge social and economic burden [4,5]. In addition, the high recurrence rate should also be taken seriously. The recurrence rate varies depending on the setting, follow-up time, diagnostic method, and race. In general, it can be as high as 20 % or more despite secondary prevention [6]. Also, the incidence and mobility of recurrent strokes is higher than that of first strokes [6]. Hospital stay may be prolonged due to recurrence in hospital, leading to a worse prognosis [7,8]. In fact, the risk of early recurrence is high, with about half of recurrent strokes occurring within days or weeks of an ischemic stroke [9,10].

Depending on the etiology, risk factors for recurrence can be classified as non-modifiable (advanced age [11] or race), modifiable or potentially modifiable factors (hypertension) [12]. Serum indicators include testosterone [13], circulating chemotactic factor CXCL12 [14], lipoprotein (a), vitamin D [15], T helper 17(Th17) cells [3], gamma-glutamyl transpeptidase (GGT) [8], proprotein convertase subtilisin/kexin type 9 (PCSK9) [16], interleukin-33(IL-33) [17]. Underlying diseases or underlying medical conditions including ischemic heart disease (IHD), diabetes mellitus, atrial fibrillation, previous stroke [10], insulin resistance [18], atherosclerosis [18], intracranial and extracranial arterial stenosis [18,19]. Controlled nutritional status (CONUT) score and prognostic nutritional index (PNI) score should be calculated [20]. Stroke characteristics include subtypes [7,10], the initial stroke severity needs to be listed [21]. Lifestyle include smoking, daily intake of fresh fruits, and sleep quality should also be taken into consideration [21].

There are a number of trials, scoring systems or models for AIS recurrence. For example, the Essen Stroke Risk Rating (ESRS) [22] is to predict the risk of recurrent stroke within a year. There are also some recurrence models based on MRI features developed, but they are not widely applicable. Davide Strambo and colleagues developed the ASTRAL recurrence score to predict the risk of r recurrence of AIS within one year. The score includs previous stroke or transient ischemic attack, stroke mechanism, pre-stroke antiplatelets, active malignancy, chronic cerebrovascular lesions on imaging, absence of early ischemic changes on first imaging. However, since Caucasians comprise the majority of the study population, additional studies are needed in non-European descendant groups [23]. In addition, Arsava et al. developed a recurrence risk estimator to predict the short-term (90 days) risk of stroke recurrence. This is an online prediction model. Assignment values were calculated based on the presence or absence of MRI (within the first 72 h) [9]. This study lays the foundation for further research on the mechanisms involved in AIS recurrence by constructing a clinical prediction model for AIS recurrence within one year, and provides precise diagnosis and treatment protocols for the clinical treatment of AIS recurrence.

2. Methods

2.1. Patients populations

A total of 645 patients with AIS treated at the second affiliated hospital of Xuzhou Medical University from August 2017 to July 2019 were enrolled. The inclusion criteria were as follows: (1) diagnosis was based on the World Health Organization criteria [24]; (2) symptoms occur within 24 h; (3) Follow-up for more than one year. Exclusion criteria were as follows: (1) Patients younger than 18 years of age; (2) patients with other serious diseases at the time of diagnosis; (3) significant lack of medical history and clinical information; and (4) other potential causes of neurological deterioration.

2.2. Data collections

Clinical data of patients meeting the inclusion and exclusion criteria were collected retrospectively. Demographic data included gender and age. Risk factors included blood pressure and blood sugar. Laboratory tests included total cholesterol, triglycerides, low-density lipoprotein (LDL), fasting serum glucose (FBG), homocysteine (HCY), uric acid (UA), fibrinogen (FIB), myoglobin (MB), c-reactive protein (CRP), D-dimer, brain natriuretic peptide (BNP), HbA1c, neuron-specific enolase (NSE), S-100β. Stroke severity (SS) was estimated on admission with the help of the National Institutes of Health Stroke Scale (NIHSS). Mild stroke was defined as an NIHSS score $\leq$8. Moderate to severe stroke was defined a NIHSS score $\geq$9 [25]. TOAST etiology types included large-artery atherosclerosis, small-vessel occlusion or fissure, cardio embolism, other identified causes and undetermined causes [7,26]. MRI features such as stroke distribution (SD), side of hemisphere (SOH), site of stroke lesion (SOS), and number of stroke lesions (NOS) were collected. Complications such as dysphagia and stroke-associated pneumonia (SAP) were collected. Treatments included thrombolysis, thrombectomy, antiplatelet, anticoagulation, statin, and proton pump inhibitor (PPI). The diagnosis of recurrence of cerebral infarction during 1 year of follow-up was based on magnetic resonance imaging showing symptomatic cerebral infarction. All the data were collected from the Second Affiliated Hospital of Xuzhou Medical University.

Table 1
Baseline data of study population.

Characteristics	Overall	No	Yes	P-value
	N = 645	N = 561	N = 84	
Age, n (%)				0.429
<60	362 (56.1)	311 (55.4)	51 (60.7)	
≥60	283 (43.9)	250 (44.6)	33 (39.3)	
Gender, n (%)				0.372
Female, n (%)	263 (40.8)	233 (41.5)	30 (35.7)	
Male, n (%)	382 (59.2)	328 (58.5)	54 (64.3)	
SBP, mmHg, mean (SD)	146.2 (20.1)	146.2 (20.3)	146.2 (18.9)	0.99
DBP, mmHg, mean (SD)	85.1 (14.2)	85.0 (14.2)	86.0 (13.8)	0.513
SD, n (%)				0.482
Anterior circulation	258 (40.0)	220 (39.2)	38 (45.2)	
Posterior circulation	235 (36.4)	209 (37.3)	26 (31.0)	
Anterior/posterior circulation	152 (23.6)	132 (23.5)	20 (23.8)	
SOH, n (%)				0.014
Left	271 (42.0)	228 (40.6)	43 (51.2)	
Right	256 (39.7)	221 (39.4)	35 (41.7)	
Bilateral	118 (18.3)	112 (20.0)	6 (7.1)	
SOS, n (%)				0.716
Cortex	149 (23.1)	131 (23.4)	18 (21.4)	
Cortex-subcortex	147 (22.8)	123 (21.9)	24 (28.6)	
Subcortex	176 (27.3)	155 (27.6)	21 (25.0)	
Brainstem	100 (15.5)	89 (15.9)	11 (13.1)	
Cerebellum	73 (11.3)	63 (11.2)	10 (11.9)	
NOS, n (%)				0.37
Single stroke lesion	453 (70.2)	390 (69.5)	63 (75.0)	
Multiple stroke lesions	192 (29.8)	171 (30.5)	21 (25.0)	
Cholesterol, mmol/L, mean (SD)	5.4 (1.3)	5.4 (1.3)	5.5 (1.1)	0.331
Triglyceride, mmol/L, mean (SD)	2.2 (0.4)	2.2 (0.4)	2.2 (0.4)	0.082
LDL, mmol/L, mean (SD)	4.6 (0.8)	4.5 (0.8)	4.6 (0.7)	0.502
FBG, mmol/L, mean (SD)	5.3 (1.0)	5.3 (0.9)	5.4 (1.0)	0.612
HbA1c, %, mean (SD)	5.7 (0.4)	5.7 (0.4)	5.7 (0.4)	0.472
HCY, μmol/L, mean (SD)	16.0 (3.8)	15.4 (3.5)	20.6 (2.8)	<0.001
UA, μmol/L, mean (SD)	356.6 (75.8)	357.1 (75.6)	353.5 (78.0)	0.695
MB, ng/mL, mean (SD)	118.5 (66.8)	118.9 (66.9)	115.5 (66.2)	0.653
CRP, mg/L, mean (SD)	12.7 (6.7)	12.3 (6.4)	15.7 (8.0)	<0.001
FIB, g/L, mean (SD)	4.4 (0.6)	4.3 (0.6)	4.4 (0.6)	0.622
Ddimer, ng/mL, mean (SD)	179.7 (59.9)	179.9 (57.7)	177.9 (73.0)	0.804
BNP, pg/mL, mean (SD)	117.0 (61.4)	116.4 (60.1)	121.5 (69.5)	0.523
NSE, ng/mL, mean (SD)	15.9 (3.6)	15.8 (3.6)	17.0 (3.4)	0.004
S100β, pg/mL, mean (SD)	260.1 (45.2)	258.5 (43.4)	271.3 (54.4)	0.042
Thrombolysis, n (%)				0.47
No	448 (69.5)	393 (70.1)	55 (65.5)	
Yes	197 (30.5)	168 (29.9)	29 (34.5)	
Thrombectomy, n (%)				0.584
No	614 (95.2)	535 (95.4)	79 (94.0)	
Yes	31 (4.8)	26 (4.6)	5 (6.0)	
Antiplatelet, n (%)				0.701
No	117 (18.1)	100 (17.8)	17 (20.2)	
Yes	528 (81.9)	461 (82.2)	67 (79.8)	
Anticoagulation, n (%)				<0.001
No	553 (85.7)	495 (88.2)	58 (69.0)	
Yes	92 (14.3)	66 (11.8)	26 (31.0)	
Statin, n (%)				0.461
No	98 (15.2)	88 (15.7)	10 (11.9)	
Yes	547 (84.8)	473 (84.3)	74 (88.1)	
PPI, n (%)				0.007
No	519 (80.5)	461 (82.2)	58 (69.0)	
Yes	126 (19.5)	100 (17.8)	26 (31.0)	
Dysphagia, n (%)				0.039
No	525 (81.4)	464 (82.7)	61 (72.6)	
Yes	120 (18.6)	97 (17.3)	23 (27.4)	
SS, n (%)				<0.001
No	380 (58.9)	356 (63.5)	24 (28.6)	
Yes	265 (41.1)	205 (36.5)	60 (71.4)	
SAP, n (%)				0.182
No	494 (76.6)	435 (77.5)	59 (70.2)	
Yes	151 (23.4)	126 (22.5)	25 (29.8)	

Table 2
Univariate and multivariate Cox analysis of AIS recurrence at 1 year.

Characteristics	Univariate Cox analysis			Multivariate Cox analysis		
	HR	95%CI	P-Value	HR	95%CI	P-Value
Age, n (%)						
<60		Ref.	Ref.			
≥60	0.82	(0.53–1.27)	0.377			
Gender, n (%)						
Female		Ref.	Ref.			
Male	1.28	(0.82–2.00)	0.281			
SBP, mmHg, mean (SD)	1.00	(0.99–1.01)	0.962			
DBP, mmHg, mean (SD)	1.01	(0.99–1.02)	0.499			
SD, n (%)						
Anterior circulation		Ref.	Ref.			
Posterior circulation	0.74	(0.45–1.21)	0.227			
Anterior/posterior circulation	0.88	(0.51–1.51)	0.634			
SOH, n (%)						
Left		Ref.	Ref.		Ref.	Ref.
Right	0.87	(0.56–1.36)	0.544	0.76	(0.48–1.2)	0.234
Bilateral	0.31	(0.13–0.72)	0.007	0.35	(0.15–0.84)	0.018
SOS, n (%)						
Cortex		Ref.	Ref.			
Cortex-subcortex	1.35	(0.73–2.49)	0.335			
Subcortex	0.96	(0.51–1.80)	0.895			
Brainstem	0.89	(0.42–1.89)	0.762			
Cerebellum	1.14	(0.53–2.47)	0.741			
NOS, n (%)						
Single stroke lesion		Ref.	Ref.			
Multiple stroke lesions	0.78	(0.48–1.28)	0.322			
Cholesterol, mmol/L, mean (SD)	1.08	(0.92–1.27)	0.357			
Triglyceride, mmol/L, mean (SD)	1.63	(0.95–2.78)	0.074			
LDL, mmol/L, mean (SD)	1.09	(0.81–1.48)	0.553			
FBG, mmol/L, mean (SD)	1.06	(0.85–1.33)	0.582			
HbA1c, %, mean (SD)	1.21	(0.72–2.04)	0.471			
HCY, μmol/L, mean (SD)	1.36	(1.29–1.43)	<0.001	1.38	(1.29–1.47)	<0.001
UA, μmol/L, mean (SD)	1.00	(1.00–1.00)	0.732			
MB, ng/mL, mean (SD)	1.00	(1.00–1.00)	0.694			
CRP, mg/L, mean (SD)	1.07	(1.04–1.10)	<0.001	1.04	(1.01–1.07)	0.013
FIB, g/L, mean (SD)	1.09	(0.78–1.53)	0.619			
Ddimer, ng/mL, mean (SD)	1.00	(1.00–1.00)	0.817			
BNP, pg/mL, mean (SD)	1.00	(1.00–1.00)	0.473			
NSE, ng/mL, mean (SD)	1.09	(1.03–1.15)	0.005	0.98	(0.9–1.05)	0.519
S100β, pg/mL, mean (SD)	1.01	(1.00–1.01)	0.013	1.00	(1–1.01)	0.189
Thrombolysis, n (%)						
No		Ref.	Ref.			
Yes	1.19	(0.76–1.87)	0.438			
Thrombectomy, n (%)						
No		Ref.	Ref.			
Yes	1.23	(0.50–3.05)	0.649			
Antiplatelet, n (%)						
No		Ref.	Ref.			
Yes	0.85	(0.50–1.44)	0.541			
Anticoagulation, n (%)						
No		Ref.	Ref.		Ref.	Ref.
Yes	2.87	(1.81–4.57)	<0.001	1.12	(0.65–1.94)	0.686
Statin, n (%)						
No		Ref.	Ref.			
Yes	1.33	(0.69–2.58)	0.395			
PPI, n (%)						
No		Ref.	Ref.		Ref.	Ref.
Yes	1.90	(1.20–3.02)	0.006	0.67	(0.37–1.21)	0.183
Dysphagia, n (%)						
No		Ref.	Ref.		Ref.	Ref.
Yes	1.71	(1.06–2.77)	0.028	0.67	(0.37–1.19)	0.169
SS, n (%)						
No		Ref.	Ref.		Ref.	Ref.
Yes	3.90	(2.43–6.26)	<0.001	3.66	(2.04–6.57)	<0.001
SAP, n (%)						
No		Ref.	Ref.			
Yes	1.39	(0.87–2.22)	0.166			

2.3. Statistical methods

R software was used for statistical analysis. For continuous variables that follow a normal distribution, the mean (standard deviation) was used for statistical description. For continuous variables with skewed distribution, the median [1] was used for statistical description. Numerical values and proportions were used to describe categorical variables. $P < 0.05$ was defined statistically significant. Univariate Cox regression analysis and multivariate Cox regression analysis were performed to identify factors independently associated with recurrence within one year. Nomogram models were developedon the basis of these factors. The performance of the model was estimated by receiver operating characteristic (ROC) curves, decision curve analysis (DCA), calibration curves and C-index. Threshoulds for recurrence risk scores were determined with the help of maximum selection rank statistics.

3. Results

3.1. Basic characteristics

In this study, 645 patients with AIS were examined and they all met the inclusion and exclusion criteria. Table 1 showed baseline data of all patients. 84 (13.0 %) patients with AIS recurred within 1 year and 561 (87.0 %) did not recur. No significant differences were found between the two groups in terms of age, sex and SD.Although the predominant SOH in both groups wasleft hemisphere, the difference in SOH distribution was statistically significant ($p = 0.014$). The major NOS in both groups were single stroke lesion. None of the laboratory indices were independent influences except for HCY, CRP, NSE and S100β. The difference in the proportion of dysphagia between the two groups was statistically significant (27.4 % VS 17.3 %, $p = 0.039$). The proportion of SS was greater in the recurrence group than in the non-recurrence group (71.4 % VS 36.5 %, $p < 0.001$). Among the relevant treatment indicators, anticoagulation and PPI were independent influences, whereas thrombolysis, thrombectomy, antiplatelet and statin were not.

3.2. Independent risk factors selection

We divided the patients into two groups based on recurrence within one year. To explore the differences between the two groups, Cox analysis was adopted (Table 2). After univariate Cox regression analysis, SOH, HCY, CRP, NSE, S100β, anticoagulation, PPI, dysphagia, and SS were identified as variables with $p < 0.05$. Further multivariate Cox regression analysis was done to select independent risk factors. Ultimately, SOH (right, HR = 0.76, 95 % CI = 0.48–1.2, $p = 0.234$; Bilateral, HR = 0.35, 95 % CI = 0.15–0.84, $p = 0.018$), HCY (HR = 1.38, 95 % CI = 1.29–1.47, $p < 0.001$), CRP (HR = 1.04, 95 % CI = 1.01–1.07, $p = 0.013$), and SS (yes, HR = 3.66, 95 % CI = 2.04–6.57, $p < 0.001$) were identified as independent risk factors for AIS recurrence at 1 year.

3.3. Development and evaluation of predictive model

SOH, HCY, CRP and SS were the variables included in the nomogram model. As we can see in Fig. 1, each variable is assigned a certain score. The total score can be obtained by adding the scores of each variable. There is a 1-year recurrence rate that corresponds to the total score. The C-index for this model was 0.872 (se = 0.016). Fig. 2 showed the ROC curve for this model. The AUC for the 1-year recurrence rate is 0.900, which means that the nomogram has good predictive value. In the calibration curve (Fig. 3), the x-axis represents the 1-year recurrence probability predicted by the nomogram, the y-axis represents the actual 1-year recurrence, the gray

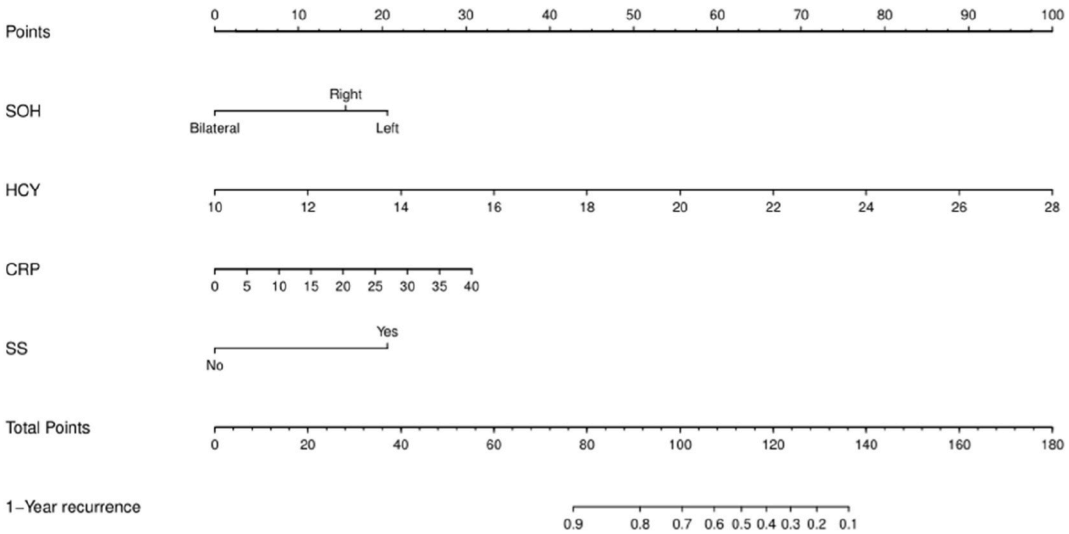

Fig. 1. nomogram of AIS of 1-Year recurrence.

line represents the ideal model, and the red line represents the observed model performance with bias corrction by bootstrap method (B = 100 repetitions). The slope of the red line is very similar to the slope of the gray line, which implies good performance of the nomogram. In the decision curve analysis (Fig. 4), the x-axis represents the risk threshold and the y-axis represents the net benefit. The model performs well except in the case of very low or high risk thresholds. The threshold values for low or high recurrence risk score were determined based on the maximum selection level statistics (Fig. 5). The study population was divided into high or low risk groups based on the total risk score calculated by the nomogram model. Cumulative risk of recurrence curves were plotted to determine a good discrimination of recurrence risk (Fig. 6).

4. Discussion

AIS poses a major threat to human health due to its heavy disease burden and susceptibility to recurrence. There are many factors that influence the recurrence of AIS. In this study, about 30 indicators are assessed to determine their impact on AIS recurreance. After statistical analysis, a nomogram model including SOH, HCY, CRP and stroke severity was developed to predict recurrence of AIS within one year.

SOH was an independent influencing factor. Left-sided strokes have a higher tendency to recur compared to right-sided and bilateral strokes. There may be two possible explanations for this phenomemon. First, injuries in the dominant hemisphere exhibit more functional impairment of brain regions than injuries in the nondominant hemisphere. The left side of the brain is the dominant hemisphere in most people. Therefore, AIS in the left brain may be more likely to recur because of more functional impairment. Second, left-brain strokes are more likely to be associated with post-stroke depression (PSD) [27]. Patients with PSD have a significantly higher rate of stroke recurrence within one year than those without PSD. PSD may make patients less proactive in participating in subsequent treatments and rehabilitations. As a result, recovery of neurological function is compromised and stroke is more likely to recur [28]. The detailed mechanisms by which stroke recurrence rates are influenced by SOH need to be further explored.

In this study, HCY, an independent risk factor for stroke recurrence, is a sulfur-containing amino acid produced by demethylation of the amino acid methionine. Hyperhomocysteinemia (HHcy) is caused by impaired methionine metabolism [29]. Many previous studies have shown that hyperhomocysteinemia is associated with cardiovascular disease, Alzheimer's disease and autoimmune disorders [30,31]. Homocysteinemia has also associated with stroke. Studies have shown that HHcy is associated with severe neurological damage, poor prognosis, PSD, and cognitive impairment [29,30]. In addition, HHcy may lead to recurrent strokes [32]. Tu et al. prospectively studied patients with AIS who were admitted to the hospital within 24 h of symptom onset. The levels of HCY in patients with AIS were significantly higher than those in control group [33].Another study compared clopidogrel plus aspirin with aspirin alone, and the first group showed a significantly decreased risk of recurrent stroke in women without HHcy [30].Hcy has a strong oxidative capacity for vascular endothelial cells and can disrupt vascular integrity and cerebrovascular permeability [34].As a result, atherosclerosis is accelerated [33].Hcy also disrupts the normal coagulation mechanism and increases the chance of thrombosis [35]. Based on these mechanism, Hcy may promote the recurrence of stroke. Hcy levels may be regulated by folic acid, vitamin B6 and vitamin B12. Therefore, Hcy may be a potential therapeutic target [31,33]. CRP is an independent risk factor. CRP, an important biomarker of inflammation, can activate the complement cascade through a positive feedback mechanism. CRP also triggers leukocyte chemotaxis and adhesion molecule expression. It is involved in maintaining and enhancing cerebrovascular inflammation and brain injury [33]. As for the relationship with AIS, CRP is an independent risk factor and indicator of poor prognosis [35]. In the study by Zhang and colleagues, 38 % of recurrent stroke patients had elevated CRP levels and 91.5 % had HHcy [36]. Inflammation plays a key

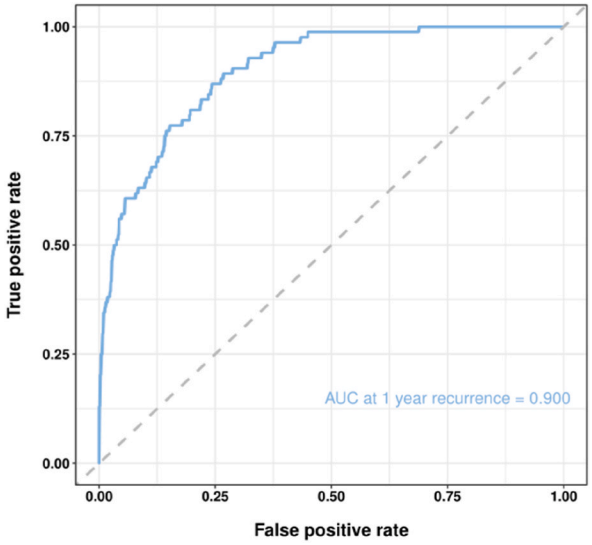

Fig. 2. ROC curve at 1-Year recurrence of nomogram model.

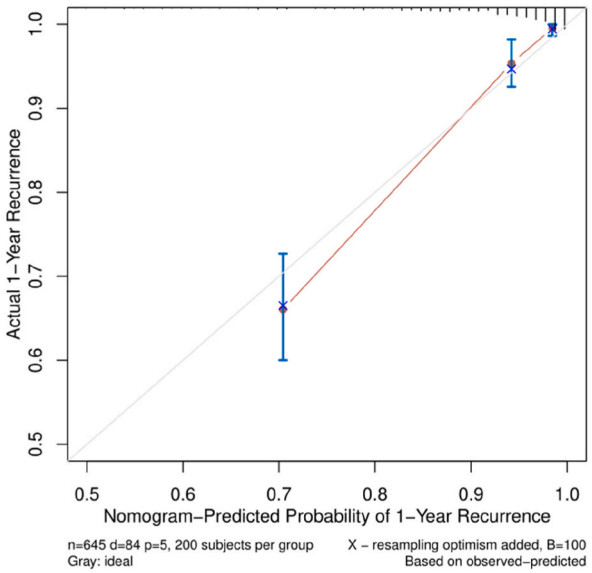

Fig. 3. Calibration curve of nomogram model.

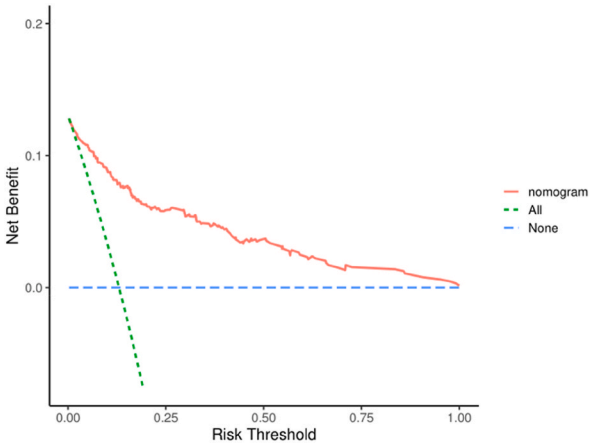

Fig. 4. Decision curve analysis of nomogram model.

role in the development and recurrence of stroke [37]. Potential mechanisms include atherosclerosis, plaque rupture, thrombosis and subsequent vascular events [19,38].

SS is an independent risk factor. SS is determined according to the NIHSS. The NIHSS score includes consciousness, gaze, visual field, facial paralysis, upper and lower limb movement, limb ataxia, sensation, speech, dysarthria, neglect [39].The NIHSS score is a practical reflection of the patient's neurological impairment. When a patient undergoes a physical examination, the clinician can quickly perform the NIHSS score. The score is highly reliable and can be used to assess the severity of the disease, treatment outcome, and prognosis. The degree of neurological damage is positively correlated with the NIHSS score and the likelihood of recurrence. Previous studies have shown that the severity of the initial stroke may also increase the likelihood of recurrence [21]. In the study by Yu Wang et al., the proportion of patients with AIS with a negative DWI gradually decreased as the NIHSS score increased. Negative DWI was associated with a reduced risk of stroke recurrence within 1 year (HR = 0.63, 95 % CI = 0.49–0.82) [40].

This study has some limitations. All data were from a single center, which may lead to bias. The baseline data, such as atrial fibrillation and patent foramen ovale, were not fully included. Monitoring of paroxysmal atrial fibrillation is difficult and was therefore not included. Cerebral infarct lesions in this study were assessed by MRI and TOAST. There are many factors associated with stroke recurrence, and this study focused only on the most important new lesions; old lesions were not discussed. This study needs to be further validated in a multicenter study population.

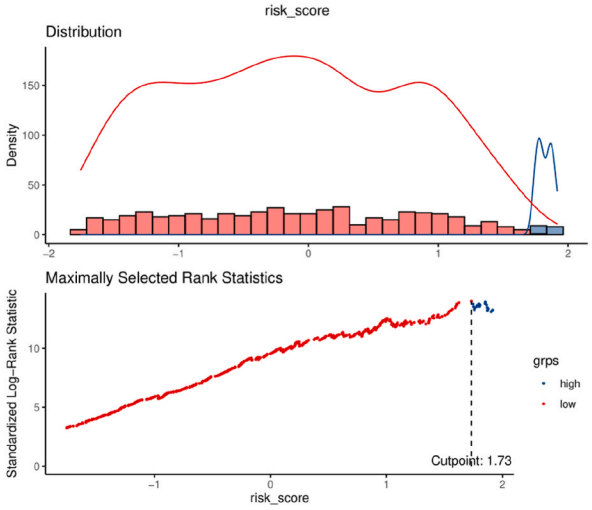

Fig. 5. Risk distribution density curve and maximally selected rank statistics.

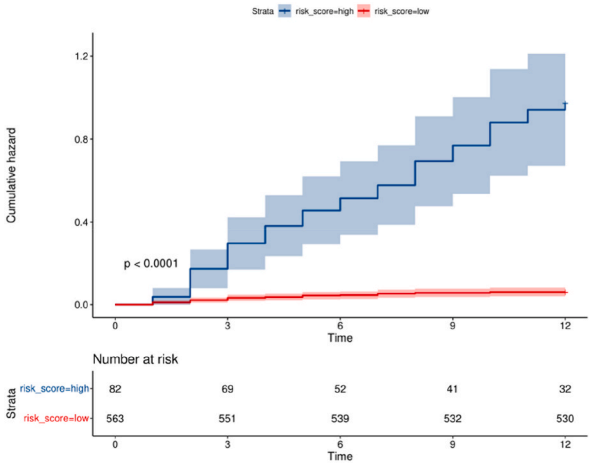

Fig. 6. Risk stratification for recurrence cumulative hazard.

5. Conclusion

In this study, a nomogram model of one-year recurrence in patients with AIS was developed, which involves laboratory indicators, clinical scores and cranial MRI features. It can be used as a guide for clinical workup. It can enhance the follow-up and management of AIS patients at high-risk of relapse. With the help of this model, recurrence of AIS is expected to be detected early.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Second Affiliated Hospital of Xuzhou Medical University. Informed consent was obtained from all patients.

Data availability statement

The data used in this study are available from the corresponding authors upon request.

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CRediT authorship contribution statement

Wenle Li: Visualization, Validation, Methodology. **Zhendong Ding:** Writing – review & editing, Validation, Software, Methodology. **Liangqun Rong:** Validation. **Xiu'e Wei:** Validation. **Chenyu Sun:** Validation, Software. **Scott Lowe:** Validation, Supervision, Investigation. **Muzi Meng:** Supervision, Formal analysis. **Chan Xu:** Methodology, Investigation. **Chengliang Yin:** Project administration, Investigation, Formal analysis. **Haiyan Liu:** Visualization, Validation, Conceptualization. **Wencai Liu:** Software, Methodology, Formal analysis. **Qian Zhou:** Writing – original draft, Conceptualization. **Kai Wang:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Kai Wang reports administrative support, article publishing charges, equipment, drugs, or supplies, statistical analysis, travel, and writing assistance were provided by Scientific Research Project of Jiangsu Health Committee (No.H2019054). Kai Wang reports administrative support, article publishing charges, equipment, drugs, or supplies, statistical analysis, travel, and writing assistance were provided by Xuzhou Science and Technology Planning Project (No. KC21220). Kai Wang reports administrative support, equipment, drugs, or supplies, and statistical analysis were provided by Development Fund of Affiliated Hospital of Xuzhou Medical University (No.XYFY2020013). Wenle Li reports statistical analysis was provided by Shaanxi Provincial Health and Health Research Fund Project (2022E006). Qian Zhou reports writing assistance was provided by The First batch of key Disciplines On Public Health in Chongqing. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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